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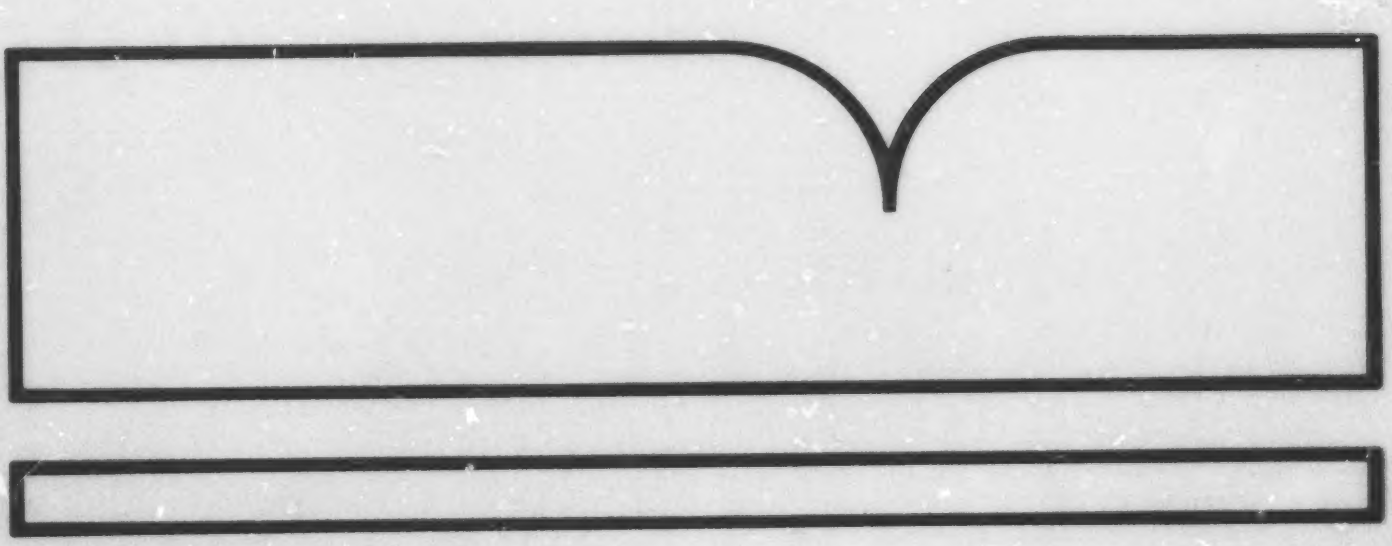

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EVALUATION OF A BENCH-SCALE DRY FLUE GAS DESULFURIZATION SYSTEM FOR SCREENING POTENTIAL REAGENTS AND OPERATING CONDITIONS

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16. ABSTRACT The paper discusses two series of bench-scale dry flue gas desulfurization (FGD) laboratory tests, the primary objective of which was to evaluate the ability of a bench-scale dry FGD system to screen potential reagents and operating conditions in support of testing at larger pilot plant or full-scale systems. The first series consisted of once-through and recycle tests with hydrated lime reagent using a laboratory spray dryer/fabric filter system rated at 0.024 cu m/s. These tests duplicated conditions in similar tests with the 2.5 MW spray dryer/fabric filter pilot plant at the EPRI Arapahoe Test Facility. In the second series, the bench-scale spray dryer/fabric filter system was modified to permit the dry injection of reagents upstream of the baghouse. This series was designed to simulate dry sorbent injection. Several sodium bicarbonate reagents and a calcium-based reagent were tested. Test results and the feasibility of using the bench-scale system for screening sorbents and operating conditions are discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
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Flue Gases	Calcium Organic Compounds	Stationary Sources	21B	
Desulfurization		Dry Flue Gas Desulfurization	07A, 07D	07C
Agents	Spray Drying		11G	13A
Selection	Coal	Fabric Filters	14G	21D
Calcium Oxides	Filtration		07B	
Combustion	Fabrics			11E

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EVALUATION OF A BENCH-SCALE DRY FLUE GAS DESULFURIZATION SYSTEM FOR SCREENING POTENTIAL REAGENTS AND OPERATING CONDITIONS

ABSTRACT

Sponsored by the Electric Power Research Institute (EPRI) and the U.S. Environmental Protection Agency (EPA), Radian Corporation has conducted two series of bench-scale dry flue gas desulfurization (FGD) laboratory tests. The primary objective of these studies was to evaluate the ability of a bench-scale dry FGD system to screen potential reagents and operating conditions in support of testing at larger pilot plant or full-scale systems.

The first series, sponsored by EPRI, consisted of once-through and recycle tests with hydrated lime reagent using a laboratory spray dryer/fabric filter system rated at 0.024 m^3/s (50 cfm). These tests duplicated conditions in similar tests with the 2.5 MW spray dryer/fabric filter pilot plant at the EPRI Arapahoe Test Facility. In the second series of tests, sponsored by EPA, the bench-scale spray dryer/fabric filter system was modified to permit the dry injection of reagents upstream of the baghouse. This test series was designed to simulate dry sorbent injection technologies. Several sodium bicarbonate reagents and

a calcium-based reagent were tested. Test results and the feasibility of using the bench-scale system for screening sorbents and operating conditions are discussed.

INTRODUCTION

The evaluation of a potential flue gas desulfurization (FGD) technology often begins with laboratory-scale proof-of-concept tests and, if warranted, progresses to bench-scale and pilot plant tests prior to full-scale demonstrations. Extensive tests are generally required at the pilot plant level due to difficulties in simulating the kinetic and equilibrium phenomena of a full-scale system in the laboratory. However, the total cost and time required to evaluate a potential FGD technology at the pilot plant level can be minimized if screening tests are conducted on a bench-scale apparatus closely simulating the crucial design and operating parameters of the pilot plant or larger system.

The U.S. Environmental Protection Agency (EPA) and the Electric Power Research Institute (EPRI) are involved in a number of programs to evaluate FGD technologies. Technologies receiving increased interest by EPA and EPRI include spray-dryer-based FGD and dry sorbent injection upstream of a fabric filter. Both technologies yield a dry by-product and thus eliminate handling and/or disposing of a wet sludge by-product.

Dry sorbent injection has the added potential to simplify hardware requirements and reduce capital costs for both new and retrofit SO_2 control applications.

EPRI and EPA each have conducted pilot plant and full-scale tests of dry FGD technologies (1-5). Radian Corporation, under separate contracts to EPRI and EPA, has conducted laboratory tests evaluating the feasibility of using a bench-scale dry FGD test apparatus for screening potential reagents and operating conditions in support of future pilot plant testing. One series of tests, conducted for EPRI, consisted of once-through and recycle spray dryer/fabric filter tests using hydrated lime. The second series of tests, conducted for EPA, involved the dry injection of sodium- and calcium-based reagents upstream of the fabric filter. Operating conditions were selected to match similar tests conducted previously in pilot plant or full-scale systems. Presented in this paper are the results of the feasibility tests and a discussion of the usefulness and limitations of the bench-scale FGD system in simulating larger systems.

EPRI SPRAY DRYER/FABRIC FILTER TESTS

Bench-Scale Test Apparatus Description

Figure 1 is a schematic of the bench-scale spray dryer/fabric filter apparatus. Major components of this apparatus are the flue gas

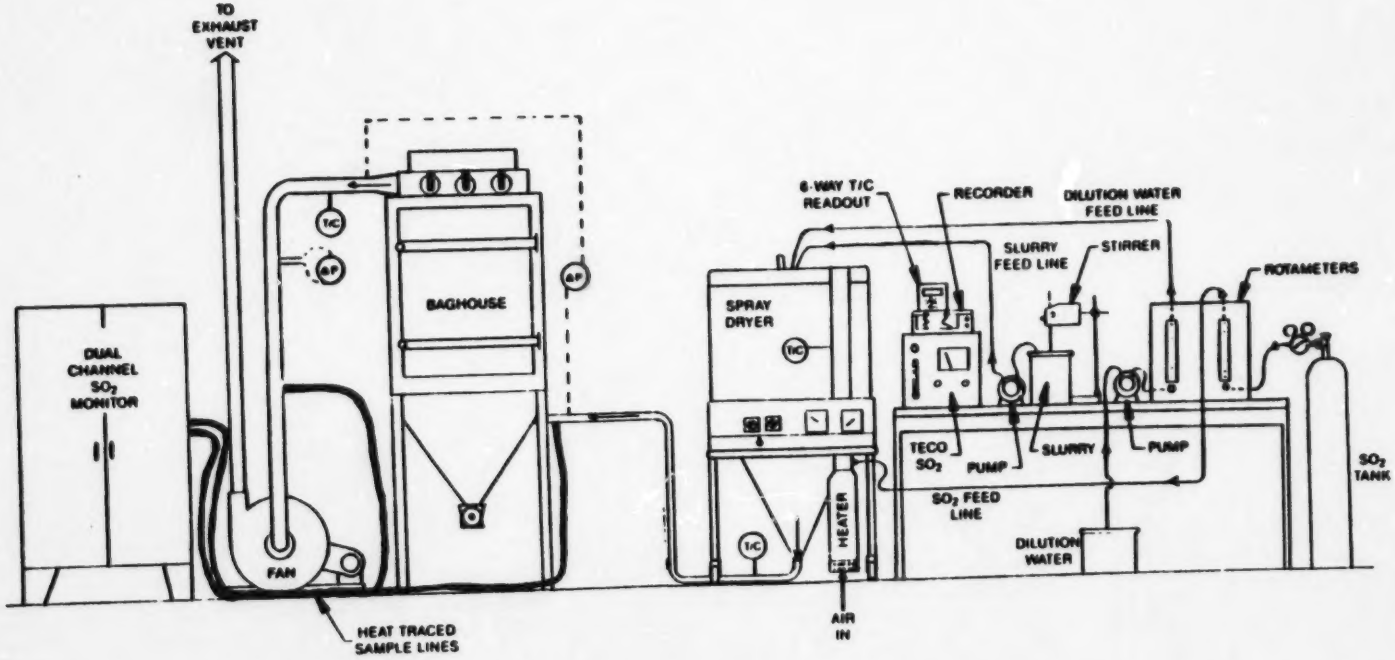

Figure 1. Bench-scale spray dryer/fabric filter experimental apparatus.

simulation system (SO_2 feed line and air), spray dryer, pulse jet fabric filter (baghouse), fan (induced draft), and process instrumentation.

Simulated flue gas is prepared in the ductwork leading to the spray dryer inlet. Room air is pulled through an electrical heating unit where the desired inlet gas temperature is attained. The heated air is then mixed with a known volume of concentrated SO_2 to achieve the desired inlet SO_2 gas concentration.

The simulated flue gas enters the 0.79 m (31 in.) diameter Niro mobile minor spray dryer chamber through an annulus around the air-driven rotary atomizer. The hot inlet flue gas dries the atomized reagent slurry droplets. Reagent slurry is fed to the atomizer by a variable-speed peristaltic pump. The reagent feed rate and the percent solids in the feed slurry are varied to obtain the desired ratio of reagent to inlet SO_2. A second peristaltic pump provides dilution water to achieve the desired approach to saturation temperature in the spray dryer. Dry solids exiting the bottom of the spray dryer enter a pulse jet fabric filter. This baghouse contains nine bags, each 0.76 m (2.5 ft) long and 0.10 m (4 in.) in diameter. The overall collection area is 2.3 m^2 (25 ft^2) giving an air-to-cloth ratio of 2:1 at the design flow rate of 0.024 m^3/s (50 cfm). The cleaning cycle for the baghouse is controlled manually. Filtered gas from the baghouse is pulled through an induced draft fan to a small stub stack for ambient discharge. The

spray dryer/fabric filter system has instrumentation necessary to monitor gas temperature, pressure, flow rate, and composition at various locations in the system.

Spray Dryer/Fabric Filter Once-Through Tests

A series of once-through tests were conducted using quicklime obtained from the Austin White Lime Company. The objectives of the tests were to pinpoint and eliminate potential operating problems and to determine how the once-through bench-scale test results compare with similar once-through tests conducted at the EPRI Arapahoe Pilot Plant test facility. Four attempts were made at conducting a 2- to 3-hour once-through test using a slurry of slaked lime. The concentration of slaked lime ($Ca(OH)_2$) in the feed slurry was adjusted to yield a molar ratio of calcium to inlet SO_2 of approximately 1:1. The atomizer head completely plugged within 45 to 60 minutes during each of the four initial attempts at lime-only tests. As a result, atomization efficiency decreased during the test, and a high percentage of the spray dried solids (25 percent) remained in the spray dryer at the end of the test. Steady state SO_2 removal rates across the spray dryer and baghouse were difficult to establish during the four once-through tests. It should be noted that excessive atomizer wheel pluggage was also noted during once-through lime tests conducted at the Arapahoe pilot plant facility (3).

Because higher weight percent solids levels reduced atomizer wheel pluggage at the Arapahoe pilot plant, an attempt was made to minimize this pluggage problem by adding neutralized Arapahoe fly ash to the feed slurry after slaking. The fly ash was first slurried and then neutralized to pH 7.0 using sulfuric acid. The resulting solids were repeatedly rinsed with deionized water to minimize the effects of free ionic species (e.g., Ca^{++} and $SO_4^{=}$) in the solids. The neutralized fly ash was added to the feed slurry in approximately a 1:1 mass ratio relative to the amount of slaked lime present. The four once-through lime tests were then repeated. The added fly ash significantly reduced the pluggage problems previously encountered with lime-only tests. In fact, almost no pluggage occurred in the atomizer head after 2 to 3 hours of operation.

Results for the once-through lime tests with neutralized fly ash added are summarized in Table 1 and are presented as dark symbols in Figure 2. Results from similar Arapahoe once-through lime tests are also included in Figure 2 as dark lines for comparative purposes. It should be noted that the Arapahoe pilot plant once-through tests did not involve addition of neutralized fly ash to the atomizer feed slurry. Based on the data presented in Figure 2, the bench-scale system and the Arapahoe spray dryer show the same general SO_2 removal trends as a function of reagent ratio. However, the overall SO_2 removal efficiency across the bench-scale system was approximately 5 to 10 percent greater

TABLE 1. BENCH-SCALE SPRAY DRYER/FABRIC FILTER TEST DATA, ONCE-THROUGH LIME TESTS WITH NEUTRALIZED FLY ASH

Test Conditions							Performance Data								
									Solids Distribution, %						
Once-Through Test Number	Gas Flow Rate m^3/s @ 322 K	Gas Flow Rate (cfm @ 120°F)	Spray Dryer Inlet Temperature K	Spray Dryer Inlet Temperature (°F)	Approach Temperature K	Approach Temperature (°F)	Spray Dryer Inlet SO_2 conc., ppm	Fresh Reagent Ratio	Spray Dryer	Baghouse Hopper	Baghouse Bags	Calcium Material Balance, %	Steady-State SO_2 Removal, % Spray Dryer	Steady-State SO_2 Removal, % Baghouse	Steady-State SO_2 Removal, % System
1	0.029	(60)	406	(270)	11	(20)	1000	0.69	15	29	56	101	60	3	63
2	0.029	(60)	406	(270)	11	(20)	1000	0.88	10	30	60	113	68	5	73
3	0.029	(60)	406	(270)	11	(20)	1000	1.36	6	40	54	101	81	13	94
4	0.024	(50)	406	(270)	11	(20)	1000	0.91	3	44	53	112	66	7	73

TABLE 2. BENCH-SCALE SPRAY DRYER/FABRIC FILTER TEST DATA 2:1 RECYCLE RATIO TESTS

Test Conditions							Performance Data								
									Solids Distribution, %						
Recycle Test Number	Gas Flow Rate m^3/s @ 322 K	Gas Flow Rate (cfm @ 120°F)	Spray Dryer Inlet Temperature K	Spray Dryer Inlet Temperature (°F)	Approach Temperature K	Approach Temperature (°F)	Spray Dryer Inlet SO_2 conc., ppm	Fresh Reagent Ratio	Spray Dryer	Baghouse Hopper	Baghouse Bags	Calcium Material Balance, %	Steady-State SO_2 Removal, % Spray Dryer	Steady-State SO_2 Removal, % Baghouse	Steady-State SO_2 Removal, % System
1-A	0.024	(50)	406	(270)	11	(20)	1000	0.97	11	33	56	99	65	7	72
1-B	0.024	(50)	406	(270)	11	(20)	1000	1.06	4	47	49	99	68	7	75
1-C	0.024	(50)	406	(270)	11	(20)	1000	1.24	5	47	48	97	67	8	75
2-A	0.024	(50)	406	(270)	11	(20)	1000	1.28	9	35	56	102	74	13	87
2-B	0.024	(50)	406	(270)	11	(20)	1000	1.24	3	36	61	98	76	15	91
2-C	0.024	(50)	406	(270)	11	(20)	1000	1.20	3	43	54	103	76	13	89
3-A	0.024	(50)	406	(270)	11	(20)	1000	0.80	10	38	52	110	70	6	76
3-B	0.024	(50)	406	(270)	11	(20)	1000	0.77	4	42	54	118	62	6	68
3-C	0.024	(50)	406	(270)	11	(20)	1000	0.76	12	41	47	118	65	5	70
4-A	0.024	(50)	406	(270)	11	(20)	1000	1.18	12	36	52	97	74	9	83
4-B	0.024	(50)	406	(270)	11	(20)	1000	1.09	6	44	50	100	74	10	85
4-C	0.024	(50)	406	(270)	11	(20)	1000	1.20	5	46	49	101	77	10	87
5-A	0.024	(50)	406	(270)	11	(20)	1000	1.45	12	28	60	101	79	15	94
5-B	0.024	(50)	406	(270)	11	(20)	1000	1.44	5	36	59	93	78	16	94
5-C	0.024	(50)	406	(270)	11	(20)	1000	1.20	3	32	65	100	65	18	83

than the SO_2 removal in the Arapahoe pilot plant operating under similar conditions. The SO_2 removal efficiency across the bench-scale spray dryer alone was approximately 10 to 15 percent greater than the SO_2 removal in the Arapahoe spray dryer, while the SO_2 removal efficiency for the bench-scale system baghouse was lower than in the Arapahoe baghouse.

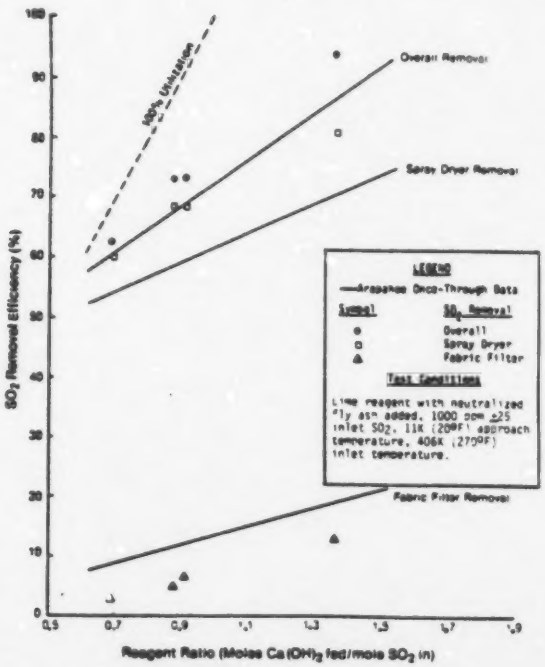

Figure 2. Bench-scale spray dryer/fabric filter performance test results, once-through lime tests with neutralized fly ash.

Use of neutralized fly ash during these tests may have biased the spray dryer SO_2 removal results high, relative to the Arapahoe pilot plant results, because increasing the feed slurry solids content theoretically results in improved atomization efficiency. Atomizer pluggage was never completely eliminated during lime-only once-through tests at

Arapahoe. The magnitude of this effect on SO_2 removal results is difficult to determine but is believed to be low.

Spray Dryer/Fabric Filter Recycle Tests

Each recycle test consisted of a series of three runs. The first run in each series (designated A) was used to generate recycle material for the next run (designated B). Product solids from Run B were used to prepare recycle material for Run C. Recycle material consisted of unreacted $Ca(OH)_2$, various calcium salts, and Arapahoe fly ash (not neutralized before use). A ratio of 2 parts (by weight) recycle solids to 1 part fresh reagent solids was used during each recycle test to simulate recycle conditions encountered at Arapahoe. The performance results for the recycle Runs B and C in each test series closely represented steady state recycle conditions; as a result, additional runs within each series were not required.

Numerous operational problems were encountered during the initial series of recycle runs, including feed line pluggage, inconsistent slurry feed rates, and feed solids settling in the feed tank and transfer lines. Steps taken to alleviate these problems included:

- sieving fly ash solids prior to use to remove large particles,

- placing baffles in the slurry feed mix tank to improve mixing,
- minimizing the dilution water flow and maximizing water in the slurry feed to reduce the solids concentration, and
- using small diameter Teflon tubing for slurry lines to increase transport velocities.

Results of the recycle tests are shown in Table 2 and Figure 3. Results from recycle Runs 1-C and 5-C in Table 2 are not presented in Figure 3 because slurry feed problems resulted in questionable steady state SO_2 removal data. Arapahoe pilot plant recycle test results are also included in Figure 3 (shaded area) for comparative purposes. Based on the results presented in Figure 3, the overall SO_2 removal efficiency for the bench-scale system approximates the Arapahoe overall SO_2 removal in most cases. The SO_2 removal across the bench-scale spray dryer was slightly greater than that of the Arapahoe spray dryer, but SO_2 removal was slightly less across the bench-scale baghouse.

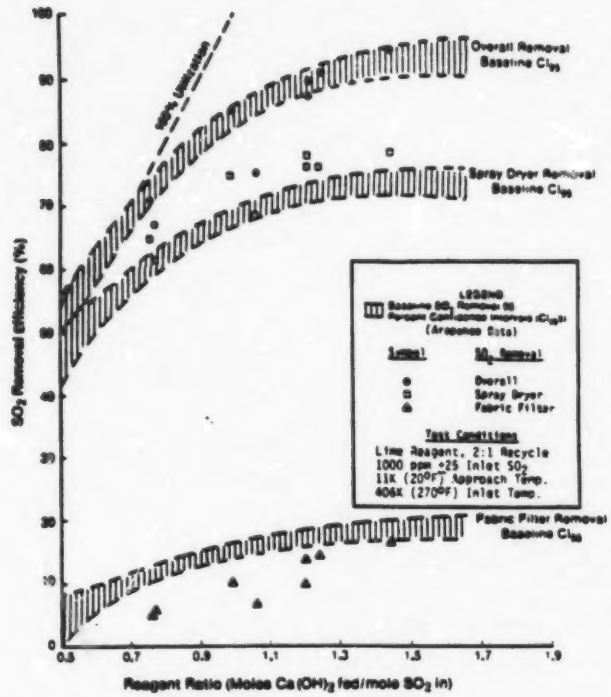

Figure 3. Bench-scale spray dryer/fabric filter performance, 2:1 recycle ratio tests.

Discussion of EPRI Bench-Scale Spray Dryer/Fabric Filter Test Results

The higher SO_2 removal levels achieved in the bench-scale spray dryer, compared to the Arapahoe spray dryer, may result in part because the bench-scale spray dryer reportedly produces an atomized slurry mean droplet size of 30 to 40 m, while empirical correlations indicate that the Arapahoe pilot unit produces a mean droplet size of 50 to 60 m. The finer droplet atomization and correspondingly increased droplet surface area per unit volume of flue gas contacted may improve SO_2 removal within the dryer vessel. Also, in many tests, a significant portion of

the spray dried solids (3 to 15 percent) was collected from the spray dryer vessel's walls after the run was completed. These solids collect because still-wet droplets are impinging on dryer walls. These solids undoubtedly contribute to spray dryer SO_2 removal, resulting in wall effects that would be reduced in larger systems. To minimize these atomization effects, the next size larger commercially available [1.2 m (4 ft) diameter] spray dryer system should be used. The larger system reportedly produces a mean product droplet size nearly the same as that calculated for the Arapahoe pilot unit spray dryer.

The lower SO_2 removal levels observed across the bench-scale fabric filter during spray drying tests are probably caused by two factors. First, the higher spray dryer SO_2 removals resulted in a lower baghouse inlet SO_2 concentration and less excess reagent in the solids entering the baghouse. Use of the larger [1.2 m (4 ft) diameter] spray dryer should help minimize these effects. Second, results of subsequent EPA dry injection tests (discussed in the next section) showed that the gas velocity immediately below the baghouse bags in the existing bench-scale baghouse is about 20 percent lower than the gas velocity that would be encountered in a typical pilot-plant or full-scale unit. Lower bench-scale fabric filter SO_2 removals may, therefore, be the result of reactive reagent solids dropping out of the flue gas stream directly into the baghouse hopper. The effect of this factor on baghouse SO_2 removal is difficult to quantify because it is not known what fraction of the

reactive solids leaving the Arapahoe spray dryer deposits on the bags rather than falling out into the hopper. Preliminary investigations indicate that a bench-scale baghouse sized for the larger spray dryer discussed earlier can be configured to approximate the baghouse gas velocity that would be encountered by larger systems. Use of such a baghouse downstream of the larger spray dryer should result in an increase in baghouse SO_2 removal efficiencies to a level comparable with that of the larger units.

EPA DRY SORBENT INJECTION TESTS

Description of Experimental Apparatus

The EPRI bench-scale spray dryer/fabric filter test apparatus used during the previous testing was slightly modified for EPA-sponsored dry injection testing. A port was installed in the ductwork downstream of the spray dryer to allow dry solids injection upstream of the baghouse. A feeder injected solids directly into the ductwork, where it contacted a simulated flue gas stream prepared at the desired gas temperature, moisture content, and SO_2 concentration in the spray dryer.

Sodium-Based Dry Injection Tests

Two series of sodium-based dry injection tests were conducted. The first series of five runs used commercially available Church & Dwight

No. 1 sodium bicarbonate ($NaHCO_3$) powder to gain experience in operating the system and to pinpoint major operating problems. Operating parameters varied during these runs included the inlet SO_2 concentration, average baghouse temperature, flue gas moisture content, and reagent solids feed rate. At the completion of each run, the solids collected in the baghouse bottom (hopper) were recovered first; then, the baghouse cleaning cycle was manually initiated a minimum of three times to ensure that the solids from the bags were effectively recovered. The baghouse hopper solids and bag solids were individually weighed to determine the fraction of solids apparently collected on the bag surfaces rather than in the hopper. Chemical analyses were performed separately on the baghouse hopper and bag-surface-collected solid samples.

Results of the first five sodium-based dry injection tests are included in Table 3. Most (70 to 90 percent) of the solids recovered from the system after testing were obtained from the baghouse hopper. Analysis of the hopper solids indicated that over 75 percent of these solids were unreacted reagent (sodium bicarbonate). However, analysis of the solids from the bags revealed that over 85 percent were either sodium sulfite or sodium sulfate, indicating that reagent utilization was high (>85 percent) for solids reaching the bags. As a result of the first series of tests, static mixers were installed in the ductwork to promote mixing of the reagent solids with the gas stream and to reduce reagent fallout prior to deposition on the bags.

TABLE 3. SUMMARY OF SODIUM-BASED DRY INJECTION FEASIBILITY TEST RESULTS

Test Number	TEST CONDITIONS: Average Fabric Filter Temperature K	(°F)	Percent Flue Gas Moisture	Flue Gas Flow Rate m^3/s	(cfm)	Average Inlet Flue Gas SO_2 Conc., ppm	Reagent Ratio Total[a]	PERFORMANCE DATA: Solids Distribution % Baghouse Bottoms	Baghouse Bags	SO_2 Removal, % Average	Steady State	Material Balance, % Sodium	Sulfur	Reagent Utilization (%) Total[a]	Baghouse Bags Only[b]
1	422	(300)	4.6	0.028	(59)	469	5.5	80	20	66	79	95	106	22	93
2	396	(250)	4.2	0.026	(56)	461	2.9	72	28	65	80	86	110	26	84
3	395	(251)	7.2	0.026	(56)	464	1.5	84	16	30	34	95	107	24	101
4	422	(300)	6.4	0.027	(57)	1860	1.8	86	14	42	50	97	106	24	100
5	396	(250)	4.6	0.030	(65)	1800	5.5	92	8	46	55	98	108	16	108
1-R1	423	(301)	5.0	0.026	(56)	455	1.2	42	58	70	69	72	93	54	96
1-R2	421	(297)	4.3	0.027	(57)	461	1.0	66	34	53	52	78	95	46	92
2-R1	396	(250)	5.0	0.028	(59)	445	1.5	43	57	82	88	81	94	58	96
2-R2	396	(250)	4.3	0.030	(63)	445	1.3	57	43	77	75	88	92	55	92
2-R3	394	(250)	4.2	0.031	(65)	451	1.4	68	32	68	70	85	94	44	95
5-R1	394	(250)	6.9	0.030	(63)	441	1.5	69	31	61	65	73	89	38	93

[a]Total Reagent Ratio and Total Reagent Utilization - based on the total molar concentration of sodium reagent fed to the system.

[b]Reagent Utilization, Baghouse Bags Only - based on sodium and sulfur analysis of baghouse bag solids.

TABLE 4. SUMMARY OF CALCIUM-BASED DRY INJECTION FEASIBILITY TEST RESULTS

Test Number	TEST CONDITIONS: Average Fabric Filter Temperature K	(°F)	Approach to Saturation Temperature K	(°F)	Percent Flue Gas Moisture	Flue Gas Flow Rate m^3/s	(cfm)	Average Inlet Flue Gas SO_2 Conc., ppm	Reagent Ratio Total[a]	PERFORMANCE DATA: Solids Distribution % Baghouse Bottoms	Baghouse Bags	SO_2 Removal, % Average	Steady State	Material Balance, % (%) Calcium	Sulfur	Reagent Utilization (%) Total[a]	Baghouse Bags Only[b]
1	321	(117)	10	(18)	5.4	0.026	(56)	445	2.7	46	54	57	45	90	104	15	22
2	322	(119)	11	(20)	6.4	0.025	(54)	1850	2.2	58	42	27	51	90	103	14	19
5	325	(121)	11	(20)	5.7	0.025	(54)	1860	1.1	49	51	15	17	93	104	18	21

[a]Total Reagent Ratio and Total Reagent Utilization - based on the total molar concentration of calcium reagent fed to the system.

[b]Reagent Utilization/Baghouse Bags Only - based on calcium and sulfur analysis of baghouse bag solids.

Size analysis of the Church & Dwight No. 1 $NaHCO_3$ powder used during these tests showed a mass mean particle diameter of 48 μm. During the second series of sodium-based dry injection tests, $NaHCO_3$ of smaller particle size was used in an effort to improve reagent deposition on the bags. Results of the second series of sodium-based dry injection tests are indicated in Table 3 by run numbers including the letter "R." Six runs were performed during the second test series under conditions similar to those of Tests 1, 2, and 3 in Table 3, except that different $NaHCO_3$ reagents were used. Runs 1-R1, 2-R1, and 2-R2 were conducted using the Church & Dwight No. 1 powder previously used, but the reagent was first ground and sieved through a 325 mesh screen. Size analysis of this reagent showed a mass mean particle diameter of 23 μm. Runs 1-R2, 2-R3, and 3-R1 used Church & Dwight's reagent 3DF, which is commercially used in fire extinguishers. The mass mean particle diameter of this reagent was measured to be 31 μm.

Placement of the static mixers in the duct between the spray dryer and baghouse and use of the finer reagent particle size resulted in an increase in both the quantity of reagent deposited on the bags and in reagent utilization. The total injected solids that collected on the bags ranged from 31 to 58 percent during the second series of tests, compared with 16 to 28 percent during the first series of tests. The overall (total) reagent utilization ranged from 38 to 58 percent during

the second test series versus 22 to 26 percent during the comparable first three runs of the initial test series. Although the overall $NaHCO_3$ utilization was substantially improved during the second series of tests, the overall utilization was not as high as the 70 to 80 percent utilization reported for full-scale demonstration tests (2,6). This suggests that efforts to increase reagent dispersion, decrease reagent particle size, and optimize baghouse design may improve the overall bench-scale reagent utilization to approach that of larger systems.

It should be noted that the baghouse bag reagent utilization was greater than 90 percent for all runs except Run No. 2 (84 percent). These data indicate that high SO_2 removal (>90 percent) can be achieved at reasonable reagent ratios if the reagent particle size permits its effective deposition on the bags. This hypothesis is substantiated by results of dry injection work sponsored by EPRI (7), that show improved reagent utilization as reagent particle size is decreased. These results, presented in Figure 4, illustrate SO_2 removal versus normalized stoichiometric ratio (NSR) when injecting $NaHCO_3$ of five average particle sizes (mass mean diameter, MMD). NSR is defined here as the moles of sodium required to react completely with the number of moles of SO_2 in the inlet flue gas.

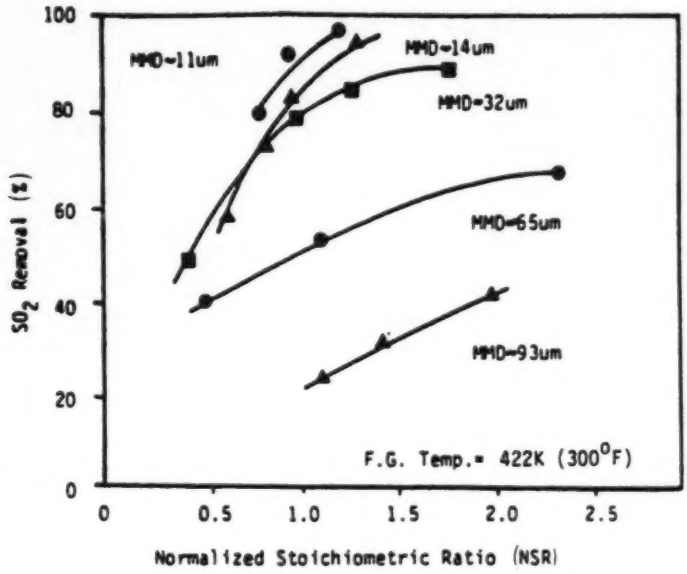

Figure 4. SO_2 removal vs. NSR for sodium bicarbonate illustrating the dependence of SO_2 on the MMD (mass mean diameter) injected into the flue gas duct. Results of work sponsored by the Electric Power Research Institute (7).

Figure 4 portrays the dependency of SO_2 removal on $NaHCO_3$ particle size. This dependency was originally thought to be fully explained by the expected increase in surface area available for reaction when using a smaller reagent particle size. However, EPRI now believes that the dependency of SO_2 removal efficiency on reagent particle size may be due more to the improved distribution of reagent onto the bags as the particle size decreases (7).

Calcium-Based Dry Injection Tests

Three calcium-based dry injection tests were conducted using Mississippi hydrated lime having a reported mass mean diameter ranging from

7 to 12 μm. The tests were conducted similar to the sodium-based tests except that additional moisture was added to the flue gas. The moisture was added to increase the flue gas relative humidity and decrease the baghouse temperature to within approximately 11K (20°F) of the adiabatic saturation temperature.

The calcium-based test results in Table 4 show the fraction of solids collected from the baghouse bags at the end of each run ranged from 42 to 54 percent and indicate that a large percentage of injected solids were not deposited on the bags. The total calcium reagent utilization ranged from about 14 to 18 percent, while the reagent utilization for the material from the bags ranged from about 19 to 22 percent. The low overall reagent utilization is due to solids not being deposited on the bags and to the relatively low reactivity of the calcium reagent compared with $NaHCO_3$ used earlier.

The steady state SO_2 removal efficiency with lime ranged from 17 percent at a reagent ratio of 1.1 (1860 ppm inlet SO_2) to 45 percent at a reagent ratio of 2.7 (445 ppm inlet SO_2). The lime reagent ratios required to achieve the levels of SO_2 removal during these runs are about 25 to 50 percent higher than anticipated based on the results of earlier pilot plant tests (8). The higher than anticipated reagent ratios

appear to be due to reagent solids not being deposited on the bags. In this respect, these results are consistent with the sodium-based bench-scale dry injection test results.

Discussion of the EPA Bench-Scale Dry Injection Test Results

Results of the sodium- and calcium-based bench-scale dry injection tests indicate that a large fraction of reagent settled out of the flue gas stream prior to deposition on the bags. Of the factors influencing reagent deposition, the velocity of the gas stream is perhaps most important. The gas transport velocity must be high enough to entrain and carry the reagent to the bags. This minimum gas transport velocity in the duct determines the aerodynamic size of the reagent solid that must be injected to ensure maximum overall reagent utilization. For example, as the duct cross-sectional area is increased, the resulting lower transport velocity requires that smaller reagent particles be injected in order to maintain similar utilization.

Findings of a brief review of baghouse design to determine the lowest gas velocity that might be encountered in a pilot- or full-scale baghouse system are summarized in Table 5. The gas velocities in Table 5 are based on the actual gas flow rate at design conditions and the dimensions of the baghouse ductwork or hopper area immediately below the tubesheet section, which corresponds to the lowest flue gas velocity

within the baghouse. Uniform gas flow across the ductwork was assumed in calculating the velocities.

TABLE 5. SUMMARY OF DESIGN AND OPERATING DATA FOR SEVERAL PILOT PLANT, FULL-SCALE, AND BENCH-SCALE BAGHOUSE SYSTEMS

No.	Description	Capacity MW	Gas Flow Rate m^3/s	Gas Flow Rate (cfm)	Baghouse Dimensions Below Tube Sheet m x m	Baghouse Dimensions Below Tube Sheet (ft x ft)	Minimum Gas[a] Velocity m/s	Minimum Gas[a] Velocity (ft/sec)
1	Arapahoe Spray Dryer/Baghouse Pilot Plant - Compartment "A"	2.5	3.1	(6600)	3.3 x 3.0	(10 x 10)	0.30	(1.0)
2	Aptron - Arapahoe Sodium Injection Pilot Plant	1	1.0	(2100)	2.1 x 1.2	(7 x 4)	0.37	(1.2)
3	Southwestern Power Plant	800	1110	(2.35×10^6)	12 x 21	10 units at (40 x 70)	0.43	(1.4)
4	Midwestern Power Plant	840	1410	(2.99×10^6)	12 x 21	14 units at (40 x 70)	0.40	(1.3)
5	Hikropul - Bin Vent with Niro Mobile Minor Spray Dryer (EPRI Bench-Scale)	—	0.024	(50)	0.61 x 0.61	(2 x 2)	0.061	(0.2)
6	Dustex Model T6-4-d with Niro Mobile Minor Spray Dryer (EPA Bench-Scale)	—	0.024	(50)	0.53 m diameter	(21 in. diameter)	0.12	(0.4)
7	Dustex Model T6-8-9 with Niro Utility Spray Dryer (Proposed EPRI Bench-Scale)	0.1	0.11	(235)	0.68 m diameter	(27 in. diameter)	0.30	(1.0)

[a]Minimum Gas Velocity - velocity of gas based on design gas flow rate and the dimensions of the baghouse ductwork immediately below the tube sheet.

The minimum gas velocity encountered by solids in two pilot plant and two full-scale systems, based on data in Table 5, ranged from 0.30 to 0.43 m/s (1.0 to 1.4 ft/sec). This is much higher than the mimimum velocity of 0.06 m/s (0.2 ft/sec) for the bench-scale baghouse used during this program and 0.12 m/s (0.4 ft/sec) for the baghouse scheduled for use in a recently built EPA bench-scale system. A proposed bench-scale system for EPRI would use a larger bench-scale spray dryer/baghouse system rated at 0.11 m^3/s (235 cfm) to achieve a minimum velocity

of 0.30 m/s (1.0 ft/sec). The minimum gas velocity attainable with this larger system should be more suitable for predicting the overall SO_2 removal potential in a full-scale dry FGD system.

CONCLUSIONS AND RECOMMENDATIONS

The EPRI bench-scale spray dryer/fabric filter test results suggest that the bench-scale apparatus can be used to predict the relative effects of process and/or reagent changes on larger scale operations. But, the existing apparatus may not accurately predict the spray dryer and fabric filter SO_2 removal efficiencies of larger systems. For spray dryer screening tests, it appears that more reliable SO_2 removal and reagent utilization values would be expected from a system with a larger diameter spray drying vessel and a baghouse designed with minimum velocities more closely matching those of larger systems. This appears to be achievable by basing a bench-scale system on the next larger commercially available spray dryer than that used for these tests.

The EPA bench-scale dry injection test results show that the existing baghouse is not suitable for extensive dry injection testing because the low baghouse solid transport velocities result in high solids deposition rates in the baghouse hopper. Replacing the existing baghouse

with a baghouse designed to achieve minimum transport velocities more closely matching those of larger systems should permit this 0.024 m^3/s (50 cfm) system to be effectively used.

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